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VENTILATION LOSS AND PRESSURIZATION IN THE NASA LAUNCH/ENTRY SUIT: POTENTIAL FOR HEAT STRESS

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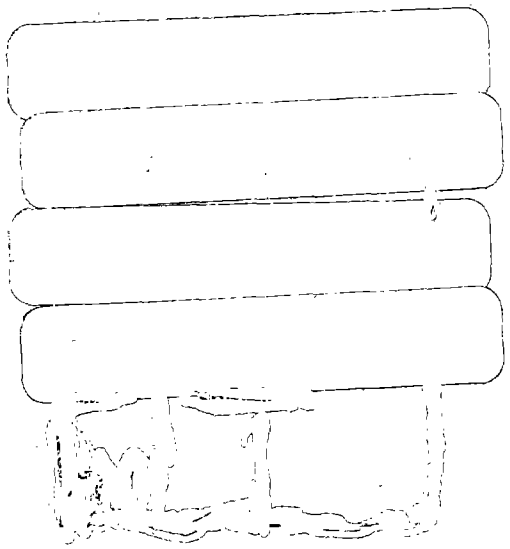

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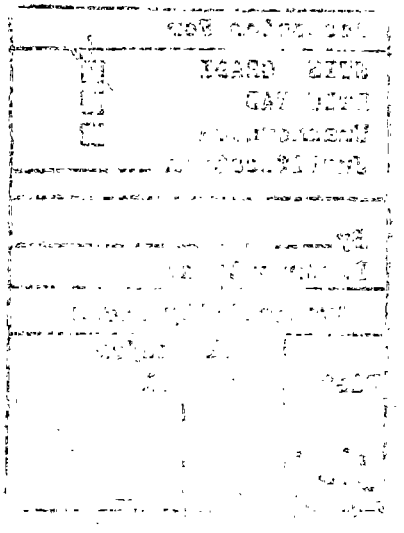

INTRODUCTION

The National Aeronautics and Space Administration (NASA) currently provides Shuttle crews with the Launch Entry Suit (LES). The LES provides both a counter pressure system, for protection against extreme hypobaria, and anti-exposure protection. Based on an expanded polytetrafluoro-ethylene (PTFE) membrane, the anti-exposure protection inherent in the LES is intended to provide thermal protection in 4.4°C (40°F) water for up to six hours.

The LES is to be worn during launch and re-entry. Accordingly, it is conceivable that a person would be required to wear the LES for up to eight hours due to a delayed launch. This could involve up to six hours awaiting launch followed by two hours of flight time until a stable orbit is reached, at which time the LES could be removed. A previous study (3) demonstrated that heat stress due to a combination of ambient conditions and clothing was unlikely to be a serious problem for Shuttle crews. However, it was thought that failure of the portable ventilator used to cool the LES, such as occurred prior to the launch of STS-26, might adversely impact mission performance. It was a further concern that should pressurization of the LES occur during reentry, heat stress might present a serious problem for crew members.

The present study was intended to determine the stress induced by the LES when used without ventilation or when pressurized under conditions of temperature and time considered extreme for Space Shuttle operations. The fully functional LES was used for comparison.

MATERIALS AND METHODS

SUBJECTS:

Four healthy individuals (Table 1), 2 females and 2 males, volunteered to participate as subjects after being fully informed of the details of the experimental protocol and associated risks. Body surface area (SA) was calculated (1) from the weight and height of each subject.

TABLE 1: Physical Characteristics of Subjects.

Subject	Gender	Age (yrs)	Height (m)	Weight (kg)	Surface Area (m^2)
A	F	23	1.65	66.0	1.73
B	M	26	1.73	76.6	1.90
C	F	34	1.65	70.6	1.78
D	M	25	1.73	70.0	1.83

METHODS:

All tests were begun in the morning, with the pressurized tests intended to last up to 45 minutes while the ventilated and unventilated trials were intended to last up to eight hours. Subjects were exposed to the experimental conditions individually. The minimum time interval between tests for a given subject was two days, so that acclimatization effects could be minimized.

Instrumentation: The subject reported to the laboratory on the morning of a test and was given a physical examination by the attending flight surgeon. Blood and urine samples were collected and analyzed as part of the flight surgeon's examination of the subject. Changes in the hydration state of subjects was evaluated by determining changes in plasma volume (%ΔPV) and red cell volume (%ΔRCV) (2) using equations 1) and 2) :

1) $$\%\Delta PV = (([Hb_1 \times (1-Hct_2)]/[Hb_2 \times (1-Hct_1)])-1) \times 100$$

2) $$\%\Delta RCV = ([(Hb_1 \times Hct_2)/(Hb_2 \times Hct_1)]-1) \times 100$$

where Hb and Hct are the hemoglobin and hematocrit measurements and the subscripts 1 and 2 represent pre- and post-exposure values. Changes in urine specific gravity (ΔSG) were determined with a clinical refractometer. Each subject's baseline weight was obtained on a scale accurate to ± 10g (Scale-Tronix, Wheaton, IL, model 6006SP). ECG electrodes (3M, Minneapolis, MN, Red Dot) were placed on the subject. ECG signals were amplified with isolated ECG amplifiers (Gould, Cleveland, Ohio, model 4600 series amplifiers). Heat flux/temperature transducers (Hamburg Assoc., Jupiter FL) were attached to the following body sites: (A) forehead; (B) left upper chest; (C) left lower upper arm; (D) left hand, dorsal; (E) right anterior thigh; (F) left posterior thigh; (G) right shin; (H) right foot; (J) right upper upper arm; and (K) left lower back. These transducers consisted of a thermopile heat flux transducer with a thermistor located in the center (Hamburg Associates, Jupiter, FL). Analog signals from these transducers were amplified (Bioinstrumentation Assoc., San Diego, CA, model HF-12/Temp-14) and stored on the laboratory's data collection system (MDB Systems, Orange, CA, model MLSI-1123C-R-X computer, Data Translation, Marlboro, MA, DT2782 A/D boards). Two rectal thermocouples (Sensortek, Clifton, NJ, model RET-1) were inserted 7 cm anterior to the anal sphincter. Thermocouple outputs were measured with isolated signal conditioners (Opto, Huntington Beach, CA, model TC.4).

Clothing: Subjects were then dressed in the LES ensemble which consisted of: 1) LES garment; 2) parachute harness; 3) parachute pack; 4) LES helmet; 5) LES gloves; 6) ventilation system; 7) capilene underwear, expedition weight; 8) adult diaper; 9) socks; 10) boots; and a lumbar pad (when requested). The ventilation system was portable and had a 10 ft^3/min (CFM) output. This ventilator was used throughout the ventilated trials and during the cool-down period following dressing in all trials. During pressurization, the LES was maintained at 2.8-3.0 lbs/in^2 (psi).

Test Procedure: Upon completion of dressing, the subject was weighed, followed by a rest period of 20 minutes which enabled the subject's temperature and heart rate to return to a resting condition before

commencing that day's trial. The laboratory temperature was maintained at approximately 20°C to minimize thermal stress during dressing.

Following the conclusion of the rest period, the subject entered the chamber and was placed in a supine position upon a Space Shuttle passenger seat (P/N 3172-13). Testing was performed in chamber conditions of dry bulb temperature (T_{db}) = 27.2 ± 0.1°C, wet bulb temperature (T_{wb}) = 21.1 ± 0.3°C, and globe temperature (T_{gl}) = 27.3 ± 0.1°C.

The helmet visor was only locked during the pressurized (Pr) trials. With the helmet visor down, breathing air entered the LES suit through a fitting on the left front leg. The subject's expired air entered the LES bladders via a one-way valve from the helmet. The subjects respiration rate determined the rate at which the suit was pressurized. The suit pressure valve maintained 2.8 psi by venting excess air from the LES bladders as the subject expired. Approximately three minutes were required to fully pressurize the LES, thus pressurized tests lasted a total of 48 minutes.

Initially for the ventilated (V) and unventilated (UV) tests, subjects were to remain supine until 6 hours had elapsed, at which time they could move to a seated position. This requirement was altered to permit intermittent periods of sitting up for approximately 5 minutes at the point a subject felt the discomfort was intolerable. The change was made because of the extreme discomfort experienced by subjects remaining supine for extended periods despite attempts at cushioning their backs. Subjects were permitted to read, listen to music, or sleep during testing; no gross movements were allowed save for the effort to sit up. Eating and drinking were ad libitum throughout the trial. Individuals were requested to remain in the chamber for eight hours, unless their exposure was terminated early due to a rectal temperature (T_{re}) exceeding 39°C, a rate of T_{re} increase of 0.6°C over a 5 minute period, heart rates exceeding 90% of the maximum predicted for age, or the subject, flight surgeon, or principal investigator requested termination. Pressurized trials had the same termination criteria.

Subjective sensations were evaluated every 30 minutes throughout the exposure period by means of scales for comfort, sweating, temperature, and fatigue. Subjects were instructed to indicate their subjective sensation for each criterion on a 1 - 7 scale. Comfort (Cm), sweating (Sw) and fatigue (Ft) used a 1 to indicate the most pleasant situation and 7 to indicate the greatest unpleasantness. Temperature (Temp) used 1 to indicate extreme cold, 3 indicated thermal neutrality, and 7 indicated extremely hot. An overall index of final subjective state (QSLT) for each run was determined from:

$$(3) \qquad QSLT = (Ft + Sw + Cm + Temp)/\ln(t_f)$$

where t_f = the time at which the final subjective data was obtained (4).

Physiological Indices: Mean weighted skin temperature (T_{sk}) was calculated using the equation:

$$(4) \qquad T_{sk} = 0.1(T_A) + 0.125(T_B+T_K) + 0.07(T_C+T_J) + 0.06(T_D) + 0.125(T_E) + 0.15(T_G) + 0.125(T_E+T_F)/2 + 0.05(T_H) \quad (°C)$$

where T_i are the measured skin temperatures at locations i = A - K (7).

The local heat transfer from skin surface to the microenvironment within the LES was determined by the measurement of energy flux across the skin surface. Mean skin surface heat flux (HF) was calculated from the equation:

(5) $HF = \Sigma HF_i$ (W/m^2)

where HF_i are the measured heat fluxes at locations i = A - K (4,5). Cumulative energy losses from the body were calculated by:

(6) $Q = \Sigma(HF \times 60 \times SA)/1000$ (kJ)

where Q is the total heat energy and SA is the body surface area. Except where indicated, the reported temperature data and energy losses were the final values obtained at the termination of runs. Temperatures and energy losses were also analyzed by comparing the changes for given intervals of runs (e.g., ΔT_{sk} calculated from T_{sk} at time t - initial T_{sk}).

Total sweat loss (SW_T) was determined by the difference between the post-test nude weight, corrected for fluid and food intake, and the pre-test weight. The change in garment weight (ΔGW) due to the uptake of sweat was determined by:

(7) $\Delta GW = (CW_2-NW_2) - (CW_1-NW_1)$ (kg)

where CW is clothed weight, NW is nude weight, and 1 & 2 signify pre- and post-test values respectively. The percentage of sweat evaporated (%E) (6) was calculated from:

8) $\%E = [(SW_T - \Delta GW)/SW_T] \times 100$ (%).

Mean sweat rate (M_{sw}) is calculated from:

9) $M_{sw} = SW_T/t$ (kg/min)

where t is elapsed time in the chamber for a given trial (6).

STATISTICAL ANALYSIS:

Differences between experimental conditions were evaluated with the nonparametric Kruskal-Wallis one-way ANOVA and Mann-Whitney U tests. Pressurized trial data are analyzed only during the period of full pressurization. Minute 0 for these runs was considered the time at which the LES reached 2.8 psi. The nonparametric Wilcoxon matched pairs test was used to compare physiological responses over time, particularly initial values with those observed at minutes 45 and 480. Differences were considered significant at the level of $p<0.05$.

Previous Study: The Kruskal-Wallis test was also used to compare the present data with physiological and anthropomorphic data from a previous study of the NASA Crew Altitude Protection System (CAPS) performed under similar environmental conditions (3). In that study, the CAPS garment, a

prototype of the LES with smaller bladders, was tested with a ventilator. The U.S. Navy CWU-62/P, an unventilated anti-exposure suit, served as the control configuration.

RESULTS

The results of this study indicate that no significant heat stress was imposed by the LES under any of the experimental conditions. While statistical differences were observed between initial values and values obtained at times during runs, these differences were not physiologically significant. Final values of T_{re}, T_{sk} (Figures 1(a), (b), and (c)), change in blood and urine osmolarity (ΔOsm_b and ΔOsm_u, respectively) (Table 2), and heart rate (Table 3) exhibited no indication of physiological stress. While considerable discomfort was reported due to prolonged immobilization and lying in essentially one position, none of the trials were terminated early.

Although no statistical differences were observed between initial and final T_{re}, a significant decrease was observed from initial T_{re} to T_{re} observed at 45 minutes ($p<0.02$). As no differences were detected among experimental conditions when T_{re} or ΔT_{re} at minute 45 were compared, the lower mean final T_{re} found in the pressurized (Pr) versus ventilated (V) or unventilated (UV) trials ($p<0.05$) was clearly a function of test duration. This was also the case for the negative overall ΔT_{re} found in the pressurized (Pr) (Figure 1(a)) versus positive ventilated (V) (Figure 1(b)) or unventilated (UV) (Figure 1(c)) trials ($p<0.05$). The observed differences among experimental conditions was due to the phenomena of cooling observed during the early period of exposure which lasted approximately 120 minutes in V (Figure 1(b)) and 60 minutes in UV (Figure 1(c)). Following the cooling period, T_{re}'s gradually rose above initial levels. The final T_{re}'s obtained during the Pr trials were in the midst of the cool-down phase (Figure 1(a)) while for the UV and V tests the values were obtained during the gradual warming (Figures 1(a) and (b)).

The subjects from the previous CAPS heat stress study (3) were significantly taller and heavier ($p<0.05$) than subjects in the current study. Inclusion of CAPS data into the analysis had no effect, with no detectable differences among conditions for ΔT_{re} determined at 45 minutes or at trial terminations (Figure 2(a)).

Initial T_{sk}'s were significantly lower than the T_{sk}'s observed at 45 minutes ($p<0.01$) and final T_{sk}'s ($p<0.01$). Unlike T_{re}, T_{sk} steadily increased from the start and then reached a plateau. The period of increase differed among the conditions. At minute 360, when subjects were permitted to sit up, there was a consistent drop in T_{sk} during the V trials which lasted until termination (Figure 1(b)). This drop was not clearly observed in the UV trials (Figure 1(c)).

The lower final T_{sk} and smaller overall ΔT_{sk} found in the Pr versus UV tests ($p<0.05$) were clearly a function of exposure duration. No statistically significant differences in T_{sk} or ΔT_{sk} were observed between any of the experimental conditions at minute 45. It was also observed that the final T_{sk} for V trials was significantly lower than for UV trials

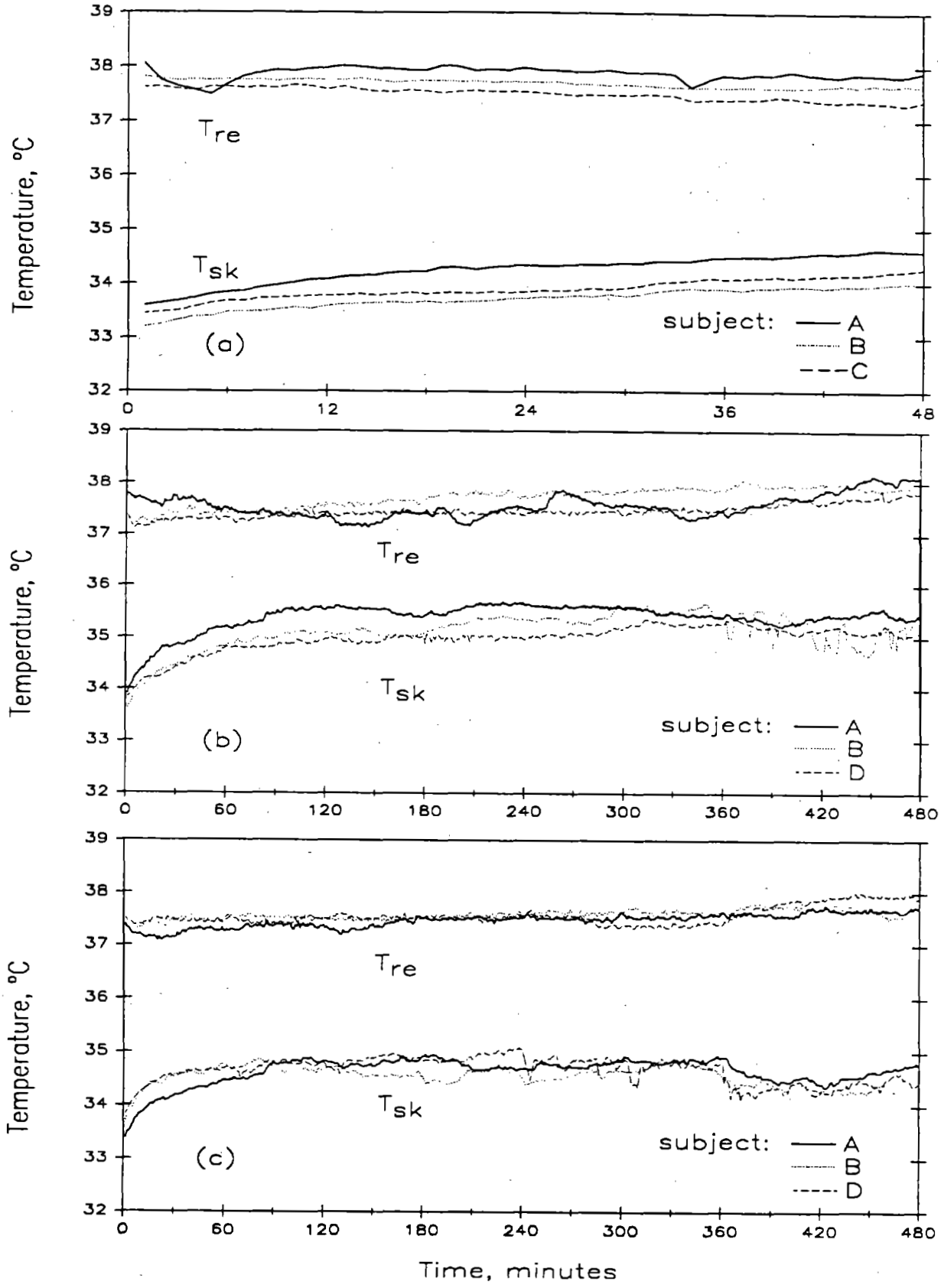

Figure 1. Rectal (T_{re}) and mean weighted skin (T_{sk}) temperatures measured during exposure to the 3 test conditions: (a) pressurized LES; (b) ventilated LES; and (c) unventilated LES.

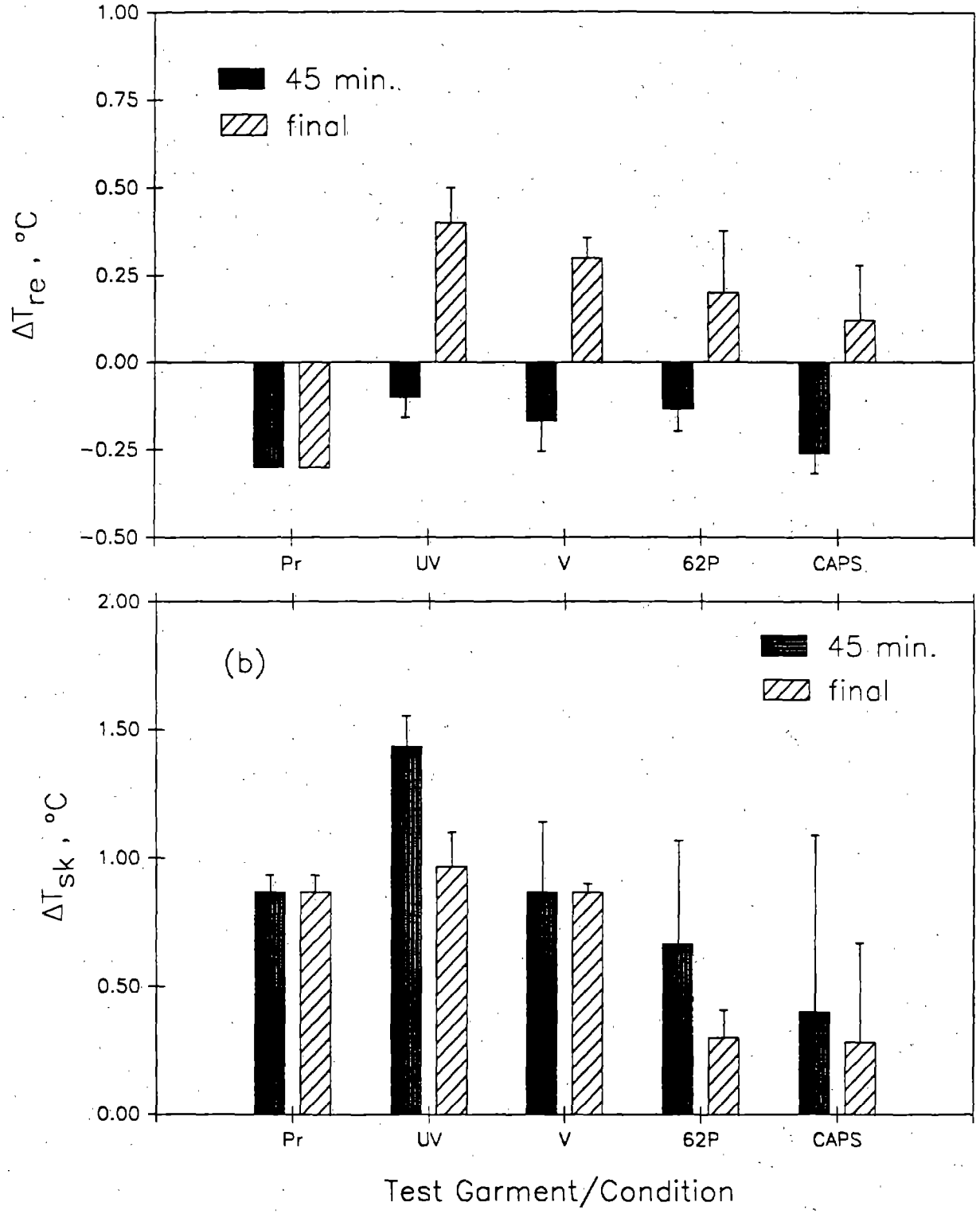

Figure 2. Calculated changes in rectal (T_{re}) and mean weighted skin (T_{sk}) temperatures during the LES exposures and from a previous study of the NASA CAPS garment under similar conditions (3). T_{re} is given after 45 and 480 minutes of exposure in (a). T_{sk} is given after 45 and 480 minutes of exposure in (b). Experimental conditions were pressurized LES (Pr); unventilated LES (UV); and ventilated LES (V). Data from the previous CAPS study is given as 62P and CAPS. Values are given as means and standard error of the mean (SEM). Note that Pr trials were terminated at 45 minutes.

($p<0.05$). Inclusion of the CAPS study (3) data had no effect on the analysis, i.e., there were still no differences among conditions for ΔT_{sk} determined at 45 minutes or at trial terminations (Figure 2(b)).

The percentage of sweat evaporated was not observed to be significantly different between experimental conditions (Table 2). A significantly larger M_{sw} was observed for the Pr versus V trials ($p<0.05$) (Table 2). SW_T for the Pr, UV, and V trials were not statistically different among experimental conditions (Table 2). Compared with the CAPS study (3), however, the Pr exposures produced significantly lower SW_T's than either of the garments tested in that study ($p<0.05$). This is not surprizing since the Pr trials had much shorter durations. The garments in the CAPS study (3) had mean SW_T's of 1.0 and 1.4 kg, respectively, over the eight hour test period. SW_T could not be analyzed at minute 45 in tests of longer durations since it was determined from change in nude weight as measured at the end of a trial.

TABLE 2. Values of physiological properties determined over trial duration. Experimental conditions were pressurized LES (Pr); unventilated LES (UV); and ventilated LES (V). NA indicates data is not available.

Condition	Subject	Water intake (ml)	M_{sw} (g/min)	SW_T (kg)	%E	%ΔPV	%ΔRCV	ΔOsmolarity (mOsm) blood	ΔOsmolarity (mOsm) urine
Pr	A	0	5.4	.50	20	-10.8	-7.1	-9	-NA
Pr	B	0	2.6	.25	0	-19.4	-5.3	NA	-33
Pr	C	0	1.1	.10	NA	-11.8	8.8	4	-224
UV	A	792	NA	NA	NA	-22.7	-10.8	39	-307
UV	B	540	1.5	.77	87	0.2	-11.2	25	104
UV	D	692	1.8	.93	82	-4.6	-4.7	27	-287
V	A	817	1.2	.60	100	-18.8	-2.3	24	-375
V	B	565	2.0	1.02	93	-1.2	9.2	-30	185
V	D	326	0.9	.44	NA	-2.1	-4.1	19	-476

Percent changes in plasma volume were found to be independent of experimental conditions (Table 2). Percent changes in red cell volume were found to be significantly higher in the V versus UV tests ($p<0.05$). The change in osmolarity of urine over trial duration, a measure of reduced water content, was found to be insignificantly changed over the course of a trial. The change in blood osmolarity was greater in the UV versus V tests ($p<0.05$), though not significantly different between the Pr and either the UV or V exposures. Final values of blood and urine osmolarity did not significantly vary between experimental conditions (Table 2).

Initial HR was found to be significantly lower than final HR ($p<0.05$) and for HR after 45 minutes of exposure ($p<0.05$). None of the final HR, however, were indicative of physiologically significant exertion or stress (Table 3). Mean final HR varied insignificantly between experimental conditions in this study when analyzed together. Inclusion of the CAPS study data (3), however, indicates that the UV trials had a significantly

higher final heart rate than the other conditions ($p<0.01$). HR differences among conditions were insignificant at minute 45 even with the inclusion of CAPS data into the analysis.

TABLE 3. Heart rates measured initially upon entry into test conditions and after 45, 360, and 480 minutes. Experimental conditions were pressurized LES (Pr); unventilated LES (UV); and ventilated LES (V). No data exist for Pr trials past the intended 45 minute end point. NA indicates data not available.

Condition		Heart Rate			
	subject	initial (bpm)	45 (bpm)	360 (bpm)	480 (bpm)
Pr	A	72	84	NA	NA
Pr	B	79	NA	NA	NA
Pr	C	90	96	NA	NA
UV	A	88	79	101	118
UV	B	100	79	90	108
UV	D	85	60	75	89
V	A	71	65	NA	92
V	B	95	83	91	94
V	D	84	73	107	99

Q's calculated for Pr, V, and UV trials at minute 45 and for UV and V trials at minutes 360 and 480 were not significantly different (Figure 3(b)). Similarly, HF measured for Pr, V, and UV tests at minutes 5 and 45 and for UV and V tests at minutes 360 and 480 were not significantly different (Figure 3(a)). However, there was a significant reduction in HF from minute 5 to minute 45 ($p<0.01$) and from minute 5 to minute 360 ($p<0.05$). No significant difference was determined for HF from minute 5 to minute 480. There were also no observed significant differences in HF between minutes 45, 360, and 480.

Subjective evaluations, both final and at minute 45, as calculated by QSLT indicated insignificant differences between the PR, UV, or V trials. Comparisons of QSLT between the UV and V exposures at minutes 360, the time at which subjects were permitted to sit upright, and 480 were also insignificantly different. The absolute value of the comfort, temperature, sweating, and fatigue scale values were observed to increase to a maximum at minute 360, followed by a reduction to lower levels by minute 480 (Table 4). This maximum response at minute 360 corresponds to subjects condition just prior to sitting up.

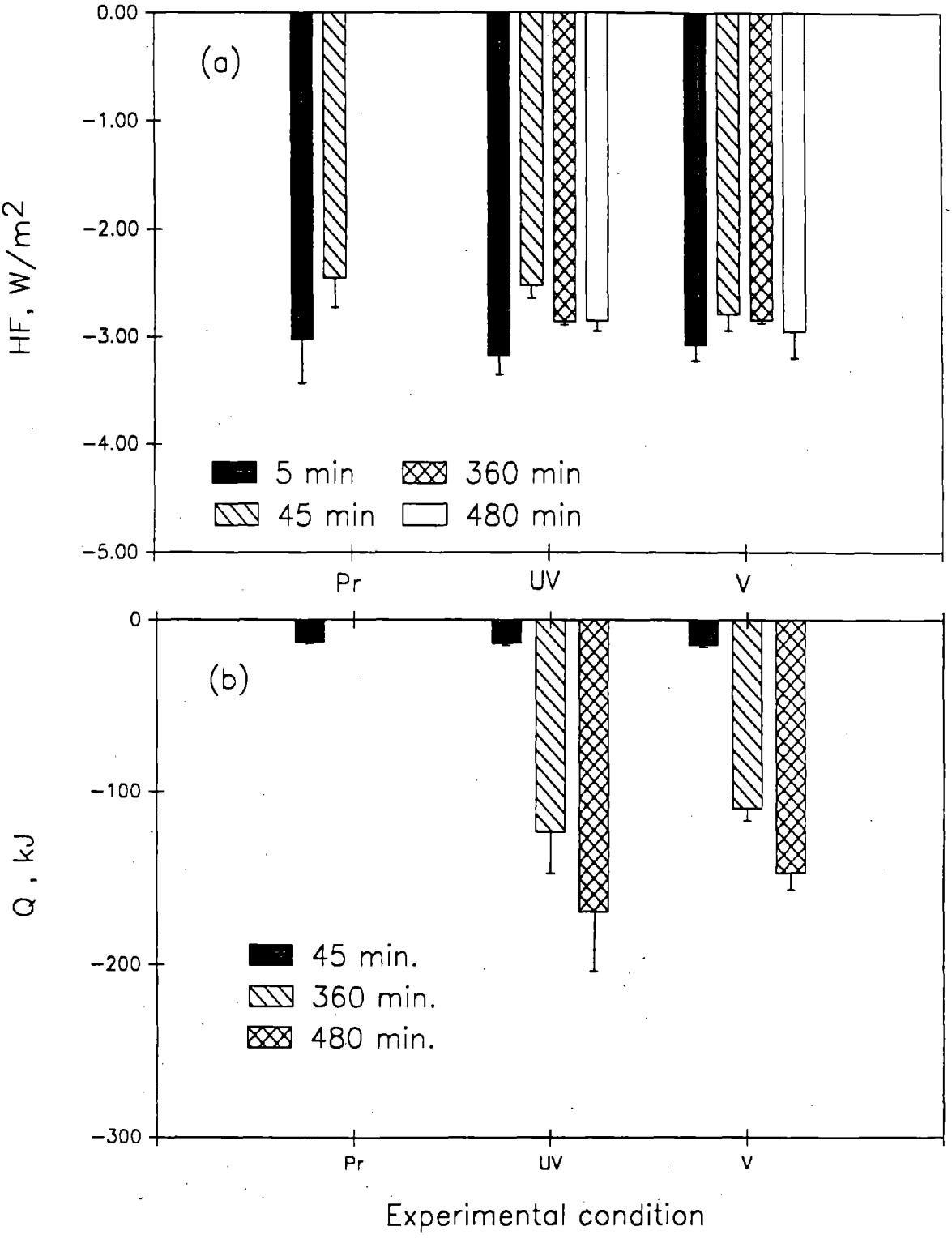

Figure 3. Measures of heat transfer during the LES exposures. Experimental conditions were pressurized LES (Pr); unventilated LES (UV); and ventilated LES (V). Values are given as means and standard error of the mean (SEM). Mean weighted skin surface heat flux is presented after 5, 45, 360, and 480 minutes of exposure in (a). Cumulative heat losses (Q) are presented after 5, 45, 360, and 480 minutes of exposure in (b). Note that the Pr trials were terminated at 45 minutes.

TABLE 4. Criteria used to evaluate subjective state of subjects. The values given were reported at approximately 30, 360, and 480 minutes of each test. Experimental conditions were pressurized LES (Pr); unventilated LES (UV); and ventilated LES (V). No data exist for Pr trials past the intended 45 minute end point. Subjective measures were reported as Comfort (C), Temperature (T), Sweating (S), and Fatigue (F). QSLT was a time-averaged mean of the subjective measures (4). NA indicates data not available.

Condition		30					360					480				
	Subject	C	T	S	F	QSLT	C	T	S	F	QSLT	C	T	S	F	QSLT
Pr	A	4	5	1	5	4.60			NA					NA		
Pr	B	4	2	2	1	2.53			NA					NA		
Pr	C	5	4	1	1	3.23			NA					NA		
UV	A	1	1	4	1	2.06	7	7	7	7	4.76	4	6	7	4	3.42
UV	B	1	4	2	1	2.35	5	6	6	5	3.79	6	7	6	5	3.89
UV	D	4	5	5	4	5.29	6	6	6	6	4.08	6	6	6	6	3.89
V	A	1	4	1	1	2.06	6	5	5	4	3.45	4	4	4	3	2.43
V	B	1	5	2	1	2.65	4	6	4	4	3.06	4	5	3	2	2.29
V	D	3	3	2	1	2.65	6	6	6	5	3.91	6	5	5	6	3.60

DISCUSSION

It is clear from the results that loss of ventilation to the LES or pressurization of the LES posed no increased heat stress risks to users of this equipment under the test conditions. While T_{re} and T_{sk} did increase during runs, their levels were never indicative of a physiological hazard. It appears that the inactivity of subjects, coupled with relatively mild ambient conditions, permitted adequate physiological adjustments to prevent thermal strain.

This lack of physiological stress is demonstrated by the relatively small changes in T_{re} and T_{sk}. At no point during any of the trials were T_{re} values observed which would indicate any physiological hazard. While the final T_{re}'s for the V and UV tests suggest some degree of heat stress, the relatively high initial T_{re}'s indicates that much of the stress was incurred in the dressing process. An elevated initial temperature might also explain the cooling which was observed, since subjects may not have fully adjusted to the initial garment microenvironment prior to the start of a trial. This is supported by the measurement of initially high HFs, which subsequently declined to a relatively constant level. The heart rates observed during trials also suggest a negligible physiological heat stress imposed on subjects, since they were only slightly elevated over initial values (Figure 1). Though the sweat losses indicated exposure to elevated temperatures, evaporation was sufficient to minimize increases in T_{re} and T_{sk}. The small increases in T_{re} and T_{sk} indicated that evaporative heat loss was sufficient to dissipate heat without accumulation within body tissues.

Much of the physiological adjustment can be attributed to the near basal state of activity in the study. This is reflected in the heart rates exhibited by the subjects (Table 3). The relatively low heart rates observed in this study would be expected for the minimal exertion required of subjects (subjects often slept in the chamber).

The observed differences in this study principally existed between the Pr versus UV and V tests. Temperature differences could be explained solely on the basis of trial duration. The effect of diminished surface blood flow during Pr trials resulting from the increased pressure on the skin surface, however, may have had some effect on T_{sk}. The larger M_{sw} (Table 2) observed in the Pr versus V trials is probably due to the hotter, at least subjectively, microenvironment encountered in the Pr trials. This could be explained by the greatly diminished air space between the garment inner surface and the subject's skin surface. This would lead to reduced amounts of convective cooling. If the overall level of cooling were to remain constant, the M_{sw} would need to increase.

During the Pr trials, subjects complained of discomfort due to restricted movement and pressure on arms and hands. Numbness was experienced in the hands and fingers, probably due to restricted blood flow. While subjects indicated that manual function was retained even after 45 minutes, at least one subject indicated considerable discomfort. Discomfort experienced in the UV and V tests was believed to be primarily due to lying on one's back without appreciable movement for 6 hours. Ventilation also appeared to cause a valve to press against the lower back, resulting in added discomfort. The level of discomfort near the end of the 6 hour period was so great that on at least one occasion the trial was nearly terminated early. The effect this had can be observed in Figure 1(b). Note the abrupt decrease in T_{sk} at minute 360 for the 3 V trials. This is thought to be due to the influx of cool air from the ventilator. The lack of such an obvious response in the UV (Figure 1(c)) would therefore be a result of no ventilation.

Water intake was in some way related to subjective comfort. It was observed that during periods of obvious discomfort drinking was minimal. Subjects would drink only minimal amounts during these periods despite encouragement. This was especially true during UV trials, though it is not evident in the QSLT data. It appeared that subjects generally consumed food and water during periods of relative comfort. This was especially true once subjects sat up. This did not impact the quantitative physiological results but clearly impacted on the ability of subjects to be alert and functional. While this type of response might be lessened with more highly fit individuals, it should be considered if circumstances require extended periods in a motionless supine position. It is worth noting that even highly fit subjects had difficulty with subjective tolerance of experimental conditions similar to those experienced in this study (3).

Changes in the design of the CAPS garment (3) led to the development of the LES. The lack of significant difference between the present study utilizing the LES versus the previously studied CAPS (3) suggests that the design modifications had no effect on thermal stress in the simulated pre-launch environment.

This study indicates that the conditions encountered in the Space Shuttle cabin during pre-launch do not act to produce heat stress, even if ventilation is not provided to users of the LES. It is also apparent that 45 minutes of pressurization at approximately 3 psi posses no hazard to personnel. The effect of the LES in the test condition, furthermore, demonstrated that no difference could be discerned between the LES and CAPS systems in this environment. Finally, the discomfort of lying motionless for 6 hours may be a cause of concern, since decreased alertness and distraction are apparent. Allowing personnel the opportunity to periodically sit up would greatly improve comfort.

CONCLUSIONS

1. Ambient temperatures of 27°C were insufficient to produce significant levels of heat stress in individuals wearing either a pressurized, ventilated, or unventilated LES ensemble.

2. Loss of ventilation in the LES, while producing greater subjective discomfort, does not significantly increase the physiological hazard for individuals wearing the LES ensemble over an 8 hour period in 27°C temperatures.

3. Over a period of 45 minutes with temperatures of 27°C, pressurization of the LES posses no greater danger with regard to heat stress than a loss of ventilation in the LES. Neither condition represents an increased hazard over a ventilated LES at this temperature.

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The potential of the National Aeronautics and Space Administration Launch/Entry Suit (LES) for producing heat stress in a simulated Space Shuttle cabin environment has been studied. The testing was designed to identify potential heat stress hazards if the LES were pressurized or if ventilation were lost. Conditions were designed to simulate an extreme pre-launch situation, with chamber temperatures maintained at dry bulb temperature = 27.2 ± 0.1°C, globe temperature = 27.3 ± 0.1°C, and wet bulb temperature = 21.1 ± 0.3°C. Two females and 2 males, aged 23-34, were employed in this study, with two subjects having exposures in all 3 conditions. Test durations in the ventilated (V) and unventilated (UV) conditions were designed for 480 minutes, which all subjects achieved. Pressurized runs (Pr) were designed for 45 minutes, which all subjects also achieved. While some significant differences related to experimental conditions were noted in rectal and mean skin temperatures, evaporation rates, sweat rates, and heart rate, these differences were not thought to be physiologically significant. The results indicate that the LES garment, in either the Pr or UV state, poses no danger of inducing unacceptable heat stress under the conditions expected within the Shuttle cabin during launch or re-entry. (JHD)

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